Chlorine

Symbol:	Cl
Atomic Number: *(protons in nucleus)*	17
Atomic Weight: *(naturally occurring)*	35

What Is It? Chlorine in its pure form is a greenish-yellow gas with a disagreeable, suffocating odor. About two and a half times denser than air, chlorine occurs in nature as two stable isotopes. (Isotopes are different forms of an element that have the same number of protons in the nucleus but a different number of neutrons.) Chlorine-35 is the most prevalent of these stable forms; it comprises about 76% of natural chlorine with chlorine-37 accounting for the rest.

Of the seven radioactive chlorine isotopes, only one – chlorine-36 – has a half-life long enough to warrant concern. The half-lives of all other chlorine isotopes are less than 1 hour. Chlorine-36 decays with a half-life of 300,000 years by emitting a beta particle and electron capture; most of the decays (98%) are by beta-particle emission. Chlorine-36 is present at the Hanford Site as a contaminant in former plutonium-production reactors that are currently being decommissioned. The long half-life of chlorine-36 (with its subsequent low-specific activity) combined with the relatively low energy of its beta particle and small amount of gamma radiation limit the hazards associated with this radionuclide.

Radioactive Properties of the Key Chlorine Isotope

Isotope	Half-Life *(yr)*	Specific Activity *(Ci/g)*	Decay Mode	Radiation Energy *(MeV)* Alpha *(α)*	Beta *(β)*	Gamma *(γ)*
Cl-36	300,000	0.033	β, EC	-	0.027	<

EC =electron capture, Ci = curie, g = gram, and MeV = million electron volts; a dash means the entry is not applicable, and a "<" means the radiation energy is less than 0.001 MeV. (See the companion fact sheet on Radioactive Properties, Internal Distribution, and Risk Coefficients for an explanation of terms and interpretation of radiation energies.) Chlorine-36 decays by both emitting a beta particle (98%) and electron capture (2%). Values are given to two significant figures.

Where Does It Come From? Chlorine is a very reactive element that does not occur uncombined in nature. It is usually found bound with elements such as sodium, potassium, and magnesium. The most common chlorine compound is sodium chloride (table salt), which is present in seawater, salt wells, and large salt deposits, often in association with other chlorides. Chlorine is produced commercially by the electrolysis of sodium chloride, and it can also be produced by oxidizing the hydrogen chloride in hydrochloric acid. Chlorine-36 is generated in the atmosphere by the spallation of argon-36 with cosmic ray protons, and in soil and rock by neutron activation of chlorine-35. Large amounts of chlorine-36 were produced by irradiating seawater during certain nuclear weapons tests conducted between 1952 and 1958.

The graphite used as a neutron moderating material in the plutonium-production reactors in the 100 Area of the Hanford Site was treated with chlorine gas at high temperatures to remove the impurity boron (which is a good neutron absorber). A small amount of chlorine remained in the graphite that was charged to the nuclear reactors. When a fissile nuclide such as an atom of uranium-235 fissions, it generally splits asymmetrically into two large fragments – fission products with mass numbers in the range of about 90 and 140 – and two or three neutrons. (The mass number is the sum of the number of protons and neutrons in the nucleus of the atom.) These neutrons can cause additional fissions (producing a chain reaction), escape from the reactor, or irradiate nearby materials. The chlorine-35 remaining in the graphite moderator absorbed neutrons to become chlorine-36. Thus, chlorine-36 is present in the graphite moderator of these shutdown reactors and in certain wastes associated with previous reactor operations as well as in wastes from ongoing decommissioning activities, including spent graphite.

How Is It Used? Chlorine has a number of industrial and commercial uses. Its primary use is as a disinfectant, and it has been used for this purpose against a wide range of life-threatening infections, viruses, and bacteria for more than 150 years. Chlorine is used to disinfect water for both drinking and swimming, and to kill harmful levels of bacteria such as *Salmonella* and *E.coli* during food processing in restaurants and in meat and poultry packaging plants. It is also used in the manufacture of bleaching powder, household cleansers, dyes, explosives, textiles, pharmaceuticals, synthetic rubber, paper and petroleum products, plastics, and poisonous gases. Chlorinated hydrocarbons have been used extensively as pesticides, and their long persistence has made them troublesome environmental pollutants. The freon refrigerants are hydrocarbons that have been reacted with chlorine and fluorine, and carbon tetrachloride and trichloroethylene are two common solvents.

What's in the Environment? Chlorine is present in crustal rock at a concentration of about 170 milligrams per kilogram (mg/kg), and its concentration in seawater is about 20 g/liter. In pure water, chlorine forms elemental chlorine (Cl_2), chloride ion (Cl-) and hypochlorous acid (HOCl). Chlorine-36 is present at Hanford as a contaminant associated with the graphite-moderated reactors. While it does preferentially adhere to soil particles, it is one of the more mobile radionuclides in soil and can move downward with percolating water to underlying soil and groundwater. Chlorine-36 is generally not a major contaminant in groundwater at Department of Energy sites, due mainly to its limited presence in wastes and soil. Its mobility combined with its long half-life makes chlorine-36 a radionuclide of potential concern for long-term management options for wastes associated with decommissioning plutonium-production reactors at the Hanford Site.

What Happens to It in the Body? Chlorine can be taken into the body by eating food, drinking water, or breathing air. Gastrointestinal absorption from food or water is the principal source of internally deposited chorine in the general population. Chorine as chloride is an essential nutrient in the human diet and is necessary for healthy nervous and digestive systems. Once taken in, chlorine-36 behaves in the body in the same manner as other chlorine isotopes. Chlorine is almost completely absorbed upon ingestion, moving quickly from the gastrointestinal tract to the bloodstream. The chlorine-36 that enters the bloodstream after ingestion or inhalation is quickly distributed to all organs and tissues of the body. Chlorine-36 is eliminated from the body with a biological half-life of 10 days.

What Are the Primary Health Effects? Chlorine is a health hazard only if it is taken into the body. External gamma exposure is not a concern because chlorine-36 decays by emitting a relatively low-energy beta particle with only a small amount of gamma radiation. While in the body, chlorine presents a health hazard from the beta particles and gamma radiation. The main health concern is the increased likelihood of cancer induction. Chlorine is also a very toxic gas, and acute exposures to high levels can cause respiratory distress and death.

What Is the Risk? Lifetime cancer mortality risk coefficients have been calculated for nearly all radionuclides, including chlorine *(see box at right)*. While the coefficients for ingestion are lower than for inhalation, ingestion is generally the most common means of entry into the body. Similar to other radionuclides, the risk coefficients for tap water are about 75% of those for dietary ingestion. In addition to its radiological carcinogenic risk, chronic ingestion of chlorine has been shown to decrease organ and body weights in animals, notably at high doses. The toxicity value for estimating the potential for non-cancer effects from chronic exposure is termed a reference dose (RfD). This is an estimate of the highest dose that can be taken in every day over a lifetime without causing an adverse health effect. The oral RfD used to estimate non-cancer effects for chlorine is 0.1 milligram per kilogram of body weight per day (mg/kg-day). This RfD was developed by analyzing the biological effects of test animals given relatively large amounts of chlorine. The results were then adjusted and normalized to a mg/kg-day basis for humans.

Radiological Risk Coefficients

This table provides selected risk coefficients for inhalation and ingestion. Maximum values are given for inhalation (no default absorption types were provided), and dietary values were used for ingestion. Risks are for lifetime cancer mortality per unit intake (picocuries, pCi), averaged over all ages and both genders (10^{-9} is a billionth, and 10^{-12} is a trillionth). Other values, including for morbidity, are also available.

Isotope	Lifetime Cancer Mortality Risk	
	Inhalation *(pCi^{-1})*	**Ingestion** *(pCi^{-1})*
Chlorine-36	9.6×10^{-11}	2.9×10^{-12}

For more information, see the companion fact sheet on Radioactive Properties, Internal Distribution, and Risk Coefficients and accompanying Table 1.

Chemical Toxicity Value
Non-Cancer Effect: ***Oral RfD***
0.1 mg/kg-day